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THE EFFECT OF JET AIRCRAFT ON AIRFORCE PAVEMENTS: INVESTIGATIONS CONDUCTED BY THE BUREAU OF YARDS AND DOCKS

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THE EFFECT OF JET AIRCRAFT ON AIRPORT PAVEMENTS: INVESTIGATIONS CONDUCTED BY THE BUREAU OF YARDS AND DOCKS

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I. The Problem

The advent of the jet-powered aircraft has, as we have seen, introduced several new problems to plague the engineer. For a number of years airfield designers were able to keep pace with aircraft designers and provide pavements which were suitable, from a structural point of view, to accommodate commercial and military aircraft. The threat of World War II and the war itself, however, caused an acceleration of activity in the aircraft industry which resulted in a need for improved pavement design standards, but the pace was too great and pavement design improvements lagged. Just as the requirements imposed by World War II aircraft were being met, the jet-powered plane came into its place of prominence, and it was found that this type of plane imposed conditions on airfield pavements which necessitated the modification or revision of many of the established concepts of pavement design. These modifications or revisions are not yet complete even though we now write specifications aimed toward combatting one or more of the effects of the ground operation of these aircraft.

By their very nature, design configuration, and geometry jet-powered aircraft have operational characteristics which cause the imposition of a set of conditions which have been found difficult to counteract. When pavements were being designed solely for the conventional propeller type aircraft the major requirement was the provision of pavement systems structurally sound enough to accommodate the greatest wheel loads expected on the surface. The jet aircraft, however, with exhaust characteristics simulating those of a giant blow torch, and having much higher tire contact pressures than were formerly used, requires that consideration be given to a number of other factors. Instead of being concerned only with the high tire pressure (which may be as high as 200 to 300 psi) it is now necessary to provide pavements to withstand the effects of gases as hot as 1500° F directed at the surface at angles up to about 15° under velocities as high as 1500 ft. per second. Fortunately, these temperatures and velocities are diminished somewhat by the time the gases strike the surface but they are still high enough to cause distress in pavements. Fuel spillage is another item of concern since it is also a cause of damage, particularly when coupled with the temperatures and velocities mentioned and when the pavement surface contains bituminous material. We have all seen, either pictorially or first hand, evidence of the damage caused by the factors mentioned so there is little need to illustrate it here.

It has been said that bituminous pavements which are composed of properly constructed, well compacted asphaltic concrete will perform satisfactorily

under jet operation. While the importance of these two factors is indisputable it has not been the experience of the Navy that by themselves proper construction and a high degree of compaction will insure a completely successful bituminous pavement, and the present design standards indicate portland cement concrete for taxiways, warm-up aprons, and for the ends of the runway - in fact for any areas which are likely to be subjected to prolonged periods of jet exhaust. For the remainder of the runway - that area which is exposed for a fleeting or very short time - it has been found that asphaltic concrete (properly constructed and well compacted) is satisfactory and its use is specified.

We are not satisfied that this design standard is the ultimate, for we recognize that "worse things are in store for us" in the form of planes whose improved performance in the air (and apparently on the ground during take-offs) will cause present aircraft to become virtually obsolete. This progress in the field of aircraft design is, of course, very desirable, but it indicates that activities and individuals concerned with airfield design, construction, maintenance, and use have a tremendous responsibility to insure that facilities are adequate in order that this progress will not be compromised.

Now, what is in store for us in the future? Not the future of fifty or one hundred years from now, but the reasonably near future, the time during which the airfields we are now constructing should be expected to be serviceable. At a conference held a year ago at Port Hueneme we were interested in learning what the aircraft manufacturers had "on the boards" in the way of plane and engine design. The consensus was something like this: We can expect planes of the reasonably near future to employ afterburning turbo-jets and rockets using solid and liquid propellants for take-off assists. This means that pavements will be exposed to temperatures in excess of 5000° F, and, in addition to the spillage of the ordinary jet fuel, they will be subjected to the action of such fuels as liquid oxygen, ammonia, alcohol, etc. Exhaust velocities will probably be as high as 8000 ft. per second and gases will impinge on pavement surfaces at angles of about 20° from tail-pipe heights of as low as one (1) foot. Tire pressures may be as high as 400 psi. Flight duration of these high performance planes will be comparatively low, so there will be more emphasis on mass take offs. This means that pavement areas will be subjected to the severe conditions more frequently. As indicated we can expect the fields we are presently designing and constructing to feel the impact of these innovations. I do not believe we can be charged with laxity if we are unable at the present to write specifications for pavements which will withstand the condition described. Materials and techniques simply are not at the stage of development where they will permit us to do so - which, of course, is the fundamental reason for our continuing research and testing program and those of other activities concerned with the problem.

II. The Program to Find the Answers

In the meantime, we still have to design and construct new fields to accommodate present aircraft and we are faced with the necessity of salvaging present fields (i.e., those built during and subsequent to World War II). Neither of these problems has been satisfactorily solved, as indicated, and we are working on the assumption that if we can establish principles and criteria upon which to base our design now, it will more than likely be possible to extend them to include conditions imposed by future aircraft.

Toward this end, the Bureau of Yards and Docks has underway at its Civil Engineering Laboratory a program of study which, it is hoped, will lead to the establishment of a rational design method. Essentially, the program consists of three principal investigations which are being carried on concurrently: (1) A search for improved materials which may be incorporated into pavement structures or placed on pavement surfaces; (2) A study of joint filling compounds and joint design; and (3) The establishment of relationship's among jet engine exhaust characteristics and pavement temperatures which will be useful in predicting effects which may be occasioned by the use of aircraft which will impose conditions more severe than is done by those planes currently in use.

The first of the principal investigations mentioned has, to date, been confined largely to laboratory studies of the refractoriness, abrasion characteristics, and other physical properties of materials found throughout the country and generally regarded to be acceptable as paving materials. These studies are being carried on for us by the Bureau of Standards in Washington and have included thus far aggregates (and concretes made therefrom) found in the eastern part of the country. An identical program is getting underway at Port Hueneme on materials of the western United States, and ultimately we intend to include all other parts of the country. The idea behind these studies is that by preliminary laboratory investigation we can determine what materials should be considered for more extensive field examination and evaluation.

Some consideration has been given also to the evaluation of materials which have been proposed by commercial activities for use as surface seals for bituminous pavements. This evaluation has been conducted under field conditions using a facility which is described below. Eleven such proprietary materials have been examined in our program at Port Hueneme and, it may be added here, none has been particularly successful even though some have shown promise. They have ranged in nature from very thin paint coats up to blocks 1-1/2 inches in thickness set in plastics. The process of evaluation for these materials is quite simple and quickly demonstrates to the vendor the manner in which his product reacts to the conditions imposed. Materials are placed on asphaltic concrete strips either by the vendor, or by our forces under the vendor's supervision, according to specifications furnished by him, and subjected to the exhaust of a jet engine for periods of time which simulate the normal ground operation of a jet plane. We start with a very flat thrust angle at a low tail-pipe height, expose the slab for a given period of time and shut off the engine; visual observations of the resulting effects are made and the thrust angle is increased. The procedure is repeated until either 15^{o} of engine inclination is reached or the material becomes ineffective. A small quantity of fuel is spilled on to the surface and again visual observations are made of the effectiveness of the proposed seal in protecting the underlying bituminous material. Figure 1 is a view of the test area taken during the evaluation of the surface seals.

As a result of the examinations we have made so far it has been concluded that in the future no materials will be evaluated under this program which do not possess appreciable thickness (say 1/4 - 1/2 inch) or which contain material which is susceptible to the solvent action of jet fuel. The heat transmission characteristics of thin paint coats in general have been found to be such that these thin coats cannot be expected to protect the underlying pavement. We believe that by taking advantage of the experience and resourcefulness of commercial activities we may be able to find a material or system of materials

which will be useful in our efforts to salvage existing bituminous pavements. Such material or materials will probably be ceramic or fire brick-like (or perhaps plastic) in nature and will, undoubtedly, be expensive. However, a consideration of the number of bituminous areas on which such materials would find application minimizes the importance of the cost, particularly when this item is weighed against the cost of removing and replacing the areas to be salvaged.

It has been said, more or less facetiously, that the only trouble with concrete pavements for jets is the compound which fills the joints between adjacent slabs. And in all seriousness this is a problem which concerns us most vitally at the moment. It is the second of the principal investigations mentioned above. We are all aware of the expense involved in joint maintenance programs at our airstrips. There has been a tremendous amount of money expended in keeping joints sealed in order that water and other foreign material will not be permitted to enter and cause distress. And to this problem we do not have a satisfactory solution. As I see it, there are three possible answers (all of which are rather obvious) to this question of joints. At Port Hueneme we are working on two of them - the third is beyond the control of the Bureau of Yards and Docks. First, a joint filling compound must be developed which will resist the action of jet exhaust. We recognize that all of the difficulty experienced with joints may not be the fault of the joint filler alone - some may be due to faulty design or configuration of the joints themselves. Perhaps with improved geometry - that is, with other depths or widths of joints, or with other depths of filling, some of the joint filling compounds may prove successful. In our program at the Laboratory we are attempting to determine whether or not this is the case. We are evaluating every known filling compound in all of the more commonly used joints, these being variously oriented with respect to the jet exhaust. At the same time our Basic Sciences Research Department is conducting preliminary investigations which we hope will lead to the development of new compounds which will be successful in sealing joints.

A second possible answer to the joint problem is that of jointless pavements. It is possible that this will be realized through the improved use of reinforcement, through prestressing, and/or through the development of concretes having better physical properties (e.g., tensile strength) than are now employed. There have actually been very few investigations carried on in the use of prestressing of thin slabs. Those that have been tried have indicated considerable success, but it is recognized that at the present stage of this technique the economics of this method of construction make it difficult to justify a recommendation along this line. It is not unlikely, however, that within a relatively short time prestressing techniques will have been developed whose costs will compare favorably with present-day conventional construction. This problem is being studied by our Structures Research Department at the Laboratory but it is too early to define the degree of success which will be obtained by their efforts. At the present time we are doing nothing in connection with improved-reinforcement design or with the development of improved concretes, but it is expected that these studies will follow those currently underway.

The third possible solution to the problem of joints is only a partial one, but it would help as far as maintenance is concerned - this is the matter of pilot training or the channelizing of traffic on fields in such a fashion that damage to joints, and to pavements in general, will be minimized. We have no definite recommendations on this as yet, but it is believed that our studies and observations will define an optimum orientation of jet exhaust on presently used joints and joint fillers.

The third principal investigation in progress under our program at Hueneme is the establishment of the relationships mentioned earlier, namely among tail-pipe height, angle of engine inclination, and pavement temperatures. We felt that knowledge of these relationships would be useful in defining, by extension or extrapolation, the conditions which would be imposed on pavements by most aircraft for some time to come. Thus, by knowing the tail-pipe height and angle of inclination of a new plane we will be able to predict with reasonable accuracy the temperatures to which pavements will be subjected.

III. The Answers to Date

Very briefly the procedure used for determining the desired relationships is as follows: We have constructed some 10' x 30' slabs of concrete, 4 inches thick, composed of materials representative of those used in paving materials in this part of the country. These slabs have thermocouples embedded in their surfaces and on the base beneath the slabs. We have an Allison J35A-5 engine (without afterburner) mounted in a test stand which permits variation of the angle of inclination while the tailpipe height is being maintained constant. Figure 2 is a view of the stand with the engine in operation. It will be noted that there are chocks under the wheels in this particular photo. This is the manner in which we are able to obtain data on runs at other than the minimum elevation permitted by the stand configuration. At the start of a series of runs the engine and carriage are placed on chocks as shown in the photo. In this position the tailpipe height is then approximately 52 inches. The angle of inclination is set at 0^{o} and the engine and a recording potentiometer are started. Surface and base temperature readings are taken during a three-minute period at 50 - 60 percent of power output, after which the power is stepped up to 100 percent and maintained for another three minutes. After the engine is stopped the potentiometer is allowed to continue to run until the peak or maximum pavement temperatures have been indicated. Periodic readings are then taken until the slab cools to a surface temperature close to what it was before the run began. The angle of inclination is increased to 2 1/2 degrees and the procedure is repeated. This continues at 2 1/2 degree increments until data are complete for angles up to 15 or 16 degrees. One set of chocks is then removed from beneath the wheels and the entire operation is repeated. Observations are made after each run of any distress which may be apparent in the form of cracks, spalling, etc., and eventually we have data covering the angles mentioned for four different tailpipe heights.

From the data collected to date we have plotted a family of curves (Figure 3) of temperature vs. angle of inclination with tailpipe height as a parameter. Of interest also are the curves of Figure 4 which indicate the temperatures obtained at various distances aft of the tailpipe for all tailpipe heights used. It is seen from these curves that the maximum surface temperature obtained was approximately 800^{o} F, and this occurred, as would be expected, under a low tailpipe height and a steep angle. Under this temperature some slight cracking of the concrete was apparent. Temperature increases indicated by the base thermocouples were so small even after a half hour as to be of little consequence.

The surface temperature would undoubtedly be much higher under afterburner operation and the effects would probably be more noticeable! We will attempt to verify this and extend the curves to include afterburner temperatures very shortly as we have an engine equipped with afterburner ready to be put into operation.

IV. Summary

Now, how are we going to use these data? You recall that earlier I mentioned a laboratory investigation of the materials of airfield construction which is currently in progress. Having established the conditions which obtain under present jet planes (and those of the near future) and the effects which are caused by these conditions, we should be able to channel our laboratory work toward the development or discovery of materials which will perform satisfactorily under field conditions. In other words, we are able to establish the criteria of efficiency or success of various materials. If we find, for example, that there are only a few materials which are successful under the conditions imposed by aircraft having, say, an angle of inclination of 15^{o} and a tailpipe height of 30 inches, while the great majority perform satisfactorily under less severe conditions, then it may be desirable or necessary to provide special ground operational areas composed of those "superior" materials for the "severe" aircraft. The remainder of the operational areas may then consist of local, generally less satisfactory, material. Similarly, where layered systems are to be utilized it is not unreasonable to envision a construction procedure wherein the top few inches of a pavement is composed of "superior" material even though the underlying layers are made up of materials which would not perform satisfactorily under the direct action of jet exhaust, but which are perfectly suitable in every other respect. In other words, while we are making a search for superior materials of construction it is doubted that they will completely exclude the use of local materials, even though the latter may not be considered "jet resistant".

Thus, through this program of study it is believed, as indicated previously, that the problems are being approached on a rational basis, and while not all the answers will be found immediately, it is hoped that the more serious ones will be - the lesser ones and the details can then be resolved.

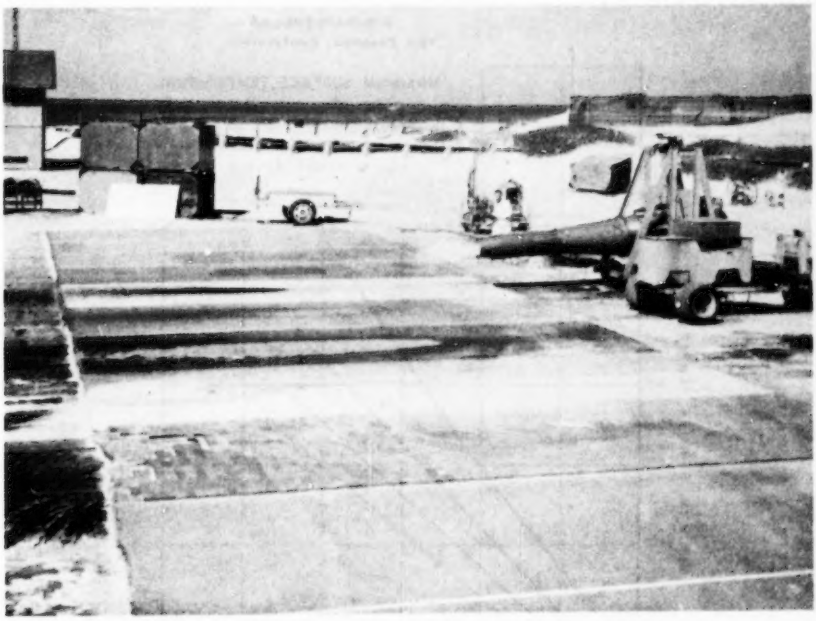

Figure 1. Evaluation of Proprietary Surface Seals

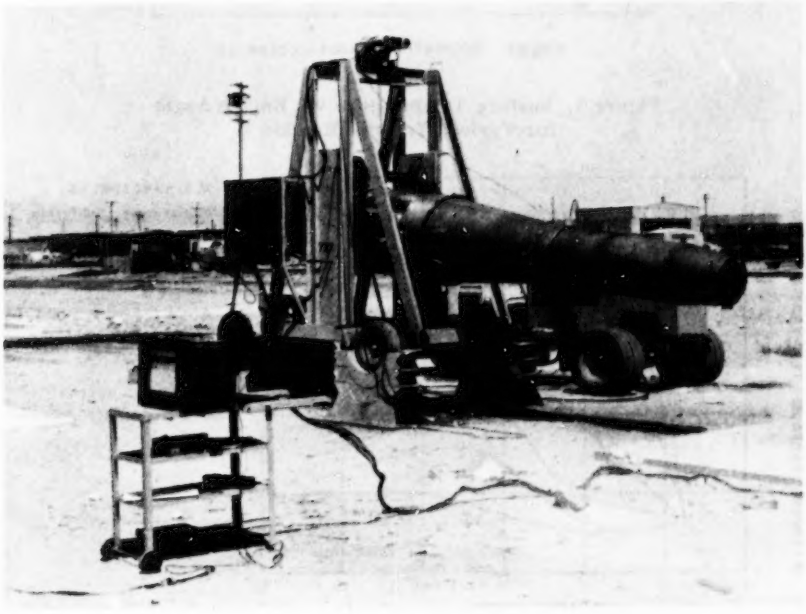

Figure 2. Allison J35A-5 Engine in Test Stand

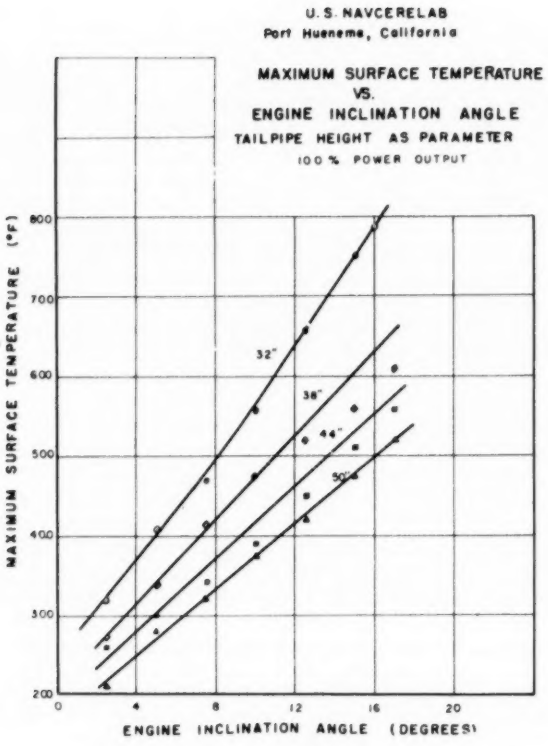

Figure 3. Surface Temperature vs. Engine Angle for Various Tailpipe Heights

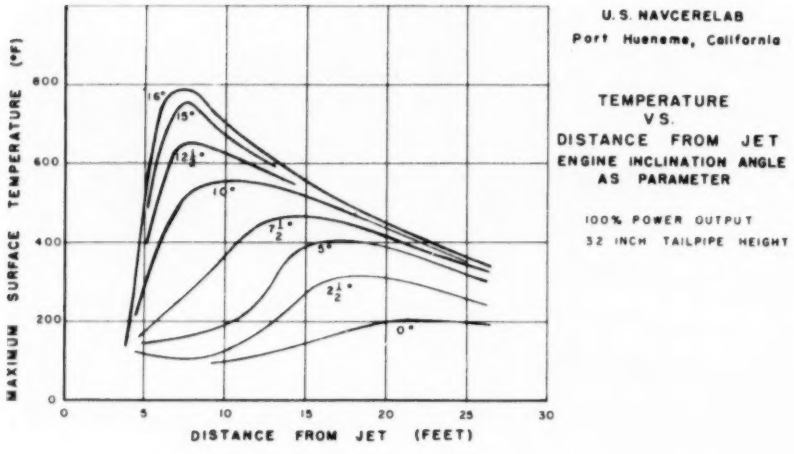

Figure 4. Surface Temperatures Aft of Tailpipe for Various Angles

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